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1 SPECIFICATION

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6 Docket No.: 96-VN-1

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BE IT KNOWN that we, Eric L. Smith and Kurt Zimmerman, citizens of the
United States residing in the State of Texas, have invented new and useful
improvements in a

METHOD AND SYSTEM FOR ASSISTING NAVIGATION USING RENDERED
TERRAIN IMAGERY

of which the following is a specification:



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FIELD OF THE INVENTION

4 The present invention relates generally to information display systems and more
5 specifically to a digital system for generating a 3-Dimensional (3-D) representation of
6 real-world terrain which closely approximates the view seen when actually looking at
7 the real-world terrain.

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BACKGROUND OF THE INVENTION

11 In the navigation of a vehicle over a prescribed route contour maps are
12 commonly used to provide an indication of the terrain over which the vehicle is
13 traveling. The information afforded by contour maps, assorted vehicle instrumentation,
14 and visual observation enables the operator to navigate the vehicle as it travels along
15 its prescribed route. Thus, a pilot navigating an aircraft, for instance, uses contour
16 maps, instrumentation readings and visual observation in order to determine altitude
17 and other course parameters have traditionally defined a navigational instrument used
18 primarily to aid in the navigation of the vehicle along a pre-defined path.

19
20 US Patent Number 4,682,160 issued to Beckwith Jr. et al. on July 21, 1987,
21 describes a system which generates a real time perspective view of the terrain lying

1 along an aircraft's flight path for the benefit of the pilot of an aircraft employing the
2 system. The system of the Beckwith, Jr. et al. patent accesses terrain data stored as
3 digital information in a digital map generator and then converts the digital data into the
4 perspective representation of the terrain which may be viewed on an appropriate
5 input/output device, such as a cockpit CRT (cathode ray tube) instrument panel. The
6 real time perspective representation provided to the pilot of the aircraft approximates
7 the view the pilot would have if actually looking out a window of the aircraft during high
8 visibility conditions.

9
10 The Beckwith et al. patent defines a hardware device that accesses terrain data
11 which is converted into a perspective representation of the terrain which is displayed on
12 a display device, such as a CRT instrument panel, for the pilot to see. The contour
13 representation of the terrain on the display device represents a perspective as if the
14 pilot were actually viewing the terrain himself during high visibility conditions. The
15 Beckwith et al. patent offers the advantage of allowing a pilot to fly during inclement
16 weather conditions with the aid of a display which provides terrain information of the
17 type that would be available to the pilot's naked eye during high visibility weather
18 conditions.

19
20 The hardware implementation of the Beckwith et al. patent produces a wire-
21 frame model of the terrain over which the aircraft is flying. The Beckwith et al. patent

1 requires a great number of contour paths in order to generate a wire-frame model of the
2 terrain is a limitation. Additionally, the hardware approach of the Beckwith et al. patent
3 does not provide as flexible a solution as could be achieved with a software approach.
4

5 US Patent Number 5,488,563 issued to Chazelle et al. on January 30, 1996
6 defines a device that correlates the terrain data with the flight path of an aircraft to
7 define an anti-collision mechanism and warning system. Memory of the device stores
8 terrain information of a very large area of the earth. As a function of the position of the
9 aircraft, the appropriate local map is temporarily transferred into a fast access memory
10 of the device and an altitude envelope of the aircraft is developed given local terrain
11 information, velocity and acceleration vectors for the zone in which the aircraft is flying.
12 The device further has anti-collision processing capabilities such that an alarm
13 indicates if the flight path of the aircraft violates a predetermined relation between a
14 protection field and the altitude envelope. The Chazelle et al. patent uses either an
15 inertial navigational unit or a radio navigational instrument to generate a synthetic
16 image representative of a flight path trajectory that will avoid collision with the terrain
17 over which the airplane is flying. The synthetic image representative of a flight path
18 trajectory is not a 3-D image of the terrain over which the airplane is flying.
19

20 The flight management technology of the Chazelle et al. patent studies terrain
21 curves in order to calculate an exit path for the airplane. The positional information

1 required in order to calculate the exit path necessarily includes flight information
2 parameters that must be supplied by the flight management system of the aircraft. This
3 is clearly shown by Informations in flight block 2 of Figure 2 of the Chazelle et al.
4 patent. Such flight parameters would include information with regard to the inertial unit
5 20, radio navigational instrument 21, and Radio-altimeter 22 all shown in Figure 3. The
6 inertial unit 20 provides information on the velocity and acceleration of the aircraft from
7 which the angle of incidence, yaw, slope, pitch, heading, and bank may be determined.
8 The angular values are used in the vicinity of the acceptable flight deck of the aircraft.

9
10 There is currently an unmet need in the art to be able to provide a navigator of a
11 vehicle with terrain information over which the vehicle is traveling regardless of weather
12 and visibility conditions in a manner that is not dependent upon trip information such as
13 velocity and acceleration of the vehicle and in a manner that is more flexible than the
14 hardware solution to be found in the prior art. There is a need in the art for the terrain
15 information to be a 3-D, non-wire frame image different from the synthetic image
16 representative of an exit path generated by the invention of the Chazelle et al. patent.
17 Additionally, there is an unmet need in the art to provide such terrain information to
18 navigators of a variety of vehicle types including, but not limited to, aircraft.

SUMMARY OF THE INVENTION

It is an object of the invention to be able to provide a navigator of a vehicle with terrain information over which the vehicle is traveling regardless of weather and visibility conditions in a manner that is not dependent upon trip information such as velocity and acceleration of the vehicle and in a manner that is more flexible than the hardware solution to be found in the prior art.

It is further an object of the invention to provide such terrain information to navigators of a variety of vehicle types, including but not limited to aircraft.

Therefore, in accordance with the present invention, a digital computer system for displaying a computer generated terrain representing a 3-dimensional depiction of the real world terrain surrounding a vehicle in real-time while the vehicle is in motion. This 3-D (3-Dimensional) image is rendered in real time while the vehicle is in motion and uses Global Positioning System (GPS) or differential GPS (dGPS) data available from a GPS unit and translates that data into virtual space within an Image Generation Processing block of the digital computer system. The digital computer system generates a virtual world 3-D image representing the eye-point position of the vehicle and directional vector into a terrain database. Using the latitude, longitude, and altitude supplied from the GPS unit as the eye point position into a virtual world using a terrain database, the device can render a depiction of the terrain outside of the vehicle, as

1 would be seen in high visibility conditions, regardless of weather, lighting and
2 atmospheric conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the claims. The invention itself, however, as well as a preferred mode of use, and further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawing(s), wherein:

Figure 1 is a block diagram of the digital computer system, according to the present invention;

Figure 2 is an illustration of the controlled and restricted zones for a particular space through which the vehicle is traveling;

Figure 3 illustrates the lighting angle condition used by the present invention;

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~~**Figure 4** illustrates the horizontal field of view and vertical field of view, according to the present invention;~~

Figure 5 illustrates the "safe-distance" bubble parameter that causes the audible and/or visual indicator to enunciate, according to the present invention; and

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Figure 6 illustrates the polygons set for 3 position points which define the 3-D virtual image, according to an embodiment of the present invention.

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DESCRIPTION OF THE INVENTION

The present invention is a digital computer system that correlates positional input data, such as Global Positioning Satellite (GPS) or differential GPS (dGPS) data, into virtual space within a computer system to generate the eye-point position of the vehicle into a simulated "real-world" image. A virtual reality image, which may be shaded or textured if so desired, is generated at a real-time rate which depicts the real-world terrain in front of the vehicle following the directional vector of travel in front of the vehicle. The computer-generated image is a view of 3-D space representing what would be viewed by the operator of the vehicle during ideal weather conditions and may be a filled polygonal image or a fractal image. The image generated by the digital computer system is viewed on an instrument panel of a vehicle which has access to the system. Thus the computer-generated image allows the operator to view the terrain in the vehicle's directional vector of travel in spite of restricted visibility conditions such as might be caused by smoke, ice, snow, rain, blizzards, nighttime.

The digital computer system of the present invention encompasses a software system that operates on a digital computer system. The digital computer system has three major components required to generate the real-time 3-D image: a database of terrain information, a 3-D render engine, and a display device for displaying the 3-D image rendered by the 3-D render engine. Reference to block diagram of the digital computer system 10 of **Figure 1** illustrates the informational flow between the three

1 major components of the digital computer system 10 of the present invention: Terrain
2 Database block 18, the render engine represented by Image Generation Processing
3 block 24, and Display block 26 through which the operator may view the rendered
4 image generated by Image Generation Processing block 24. The Display block 26
5 represents a Display device which displays for the operator the real world terrain
6 surrounding the vehicle. The computer generated scene is a view of the 3-D space
7 representing what would be viewed of the real world if viewed by the operator of the
8 vehicle during ideal weather and lighting conditions.

9
10 Position Information block 14 of the digital computer system 10 contains GPS
11 (Global Positioning Satellite) data or dGPS (differential Global Positioning Satellite)
12 data received from GPS unit 12, hereinafter referred to as GPS data. The GPS system
13 allows civilians access to twenty-four satellites in orbit around the earth. The GPS
14 system takes directional information from each of three or four of the twenty-four
15 satellites, using a 3-D triangulation measurement, in order to compute a position. It is
16 important to note that the FAA (Federal Aviation Administration), on December 7, 1995,
17 approved the use of differential GPS for instrument approaches to otherwise restricted
18 airports. This is expected to greatly expand the number of IFR rated airports in the
19 United States in the future.

1 GPS unit 12 is representative of a variety of GPS systems which use standard
2 interface protocols, such as the National Marine Equipment Association 0183 or
3 Trimble Standard Interface Protocol. The digital computer system 10 translates the
4 GPS or dGPS data into virtual space within the Image Generation Processing block 24
5 of digital computer system 10. Image Generation Processing block 24 may be any
6 image processing technology, including image processing technology commercially
7 available.

8
9 In addition to the GPS data, Image Generation Processing block 24 is provided
10 with information from the Terrain Acquisition block 20 in order to generate a computer
11 image of the terrain over which the vehicle is traveling that may be viewed at Display
12 block 26. Given the GPS data and terrain data, Image Generation Processing block 24
13 uses a render engine to generate the 3-D image. A render engine may be defined as
14 code that will generate an image based upon terrain database information and eyepoint
15 position. The computer image produced by Image Generation Processing block 24 and
16 viewed at Display block 26 represents the eye-point position and directional vector of
17 the vehicle in the simulated "real-world" image of the vehicle into the terrain database.
18 The Display device represented by Display lock 26 may be any number of appropriate
19 devices known in the art. For instance, the Display device may employ a CPU (central
20 processing unit) with an embedded operating system (O/S) and code; naturally, such a
21 Display device with embedded code must have enough RAM (random access memory)
22 in order to execute the code. The Display device may be a storage device such as a

1 CD ROM (compact disk read only memory) which stores data for the terrain database
2 over which the vehicle is traveling for that given trip. The 3-D image itself may be
3 displayed upon any display device such as an active matrix LCD (liquid crystal display)
4 screen that is located on the instrument panel of the vehicle.

5
6 As previously discussed, the positional information of Position Information block
7 14 of the vehicle is acquired from a GPS system, represented by GPS Unit 12, and is
8 used to determine the eye point position in a database of real-world terrain data. The
9 GPS system takes directional information from each of three or four satellites to
10 compute a position, using the 3-D triangulation method. GPS data or dGPS data
11 provides information concerning Latitude Degrees & Minutes, Longitude Degrees &
12 Minutes, Altitude in meters above the average/mean sea level, and Time to digital
13 computer system 10; Velocity information may or may not be available on all GPS
14 systems. The Latitude, Longitude, Altitude, and Time values may be used to define a
15 position in 3-Dimensional space which is mapped to a corresponding location in a
16 virtual reality world which will exactly mimic the real-world which actually exists outside
17 the vehicle.

18
19 Information related to the Latitude, Longitude, Altitude, Time and Velocity of the
20 vehicle, allows a 4-point spatial location, represented by (X, Y, Z, T), to be derived by
21 Location Calculations block 16 given the GPS data, where X is representative of

1 Latitude in degrees and minutes, Y is representative of Longitude in degrees and
2 minutes, Z is representative of Altitude in meters, and T is representative of time.
3 Typically, T is representative of time at a resolution of 0.5 second. The 4-point spatial
4 location is useful in determining a number of useful parameters related to the trip of the
5 vehicle. These parameters to be determined using the 4-point spatial relationship
6 include the position of the vehicle in relation to the real-world database coordinates
7 using either longitude/latitude or Universal Transverse Mercator units; the directional
8 vector of travel using the last set of coordinates including heading and pitch; and the
9 velocity, $v=d/t$, at which the vehicle is traveling.

10
11 The GPS data must be sampled periodically at short enough intervals to render
12 a reliable image of the vehicle in the terrain it is transversing. Thus, Position
13 Information block 14 of the digital computer system 10 samples GPS positional data at
14 least every $\frac{1}{2}$ second if possible or even faster if possible; if $\frac{1}{2}$ second output from the
15 GPS system is unavailable, the digital computer system 10 retrieves GPS data as
16 rapidly as it is available. The faster the sampling, the more realistic the real-time image
17 produced by Image Generation Processing block 24 will be. It will be understood by
18 one of ordinary skill in the art, therefore, that sampling may occur so frequently as to be
19 characterized as "continuous sampling" where positional input data is continuously
20 received by Position Information block 14. The Image Generation Processing block 24
21 of digital computer system 10 then draws a smooth "animation" of the movement of the
22 vehicle based upon the last known position and the speed of the vehicle.

1
2 Using the latitude, longitude, altitude, and direction of travel as the eye point
3 position for a terrain database, the digital computer system can render a depiction of
4 the terrain along the directional vector of the vehicle by referencing the last positional
5 reading in order to compute the heading and pitch of the current position of the vehicle.
6 It should be noted that location A is the next to last positional reading at time T1 while
7 location B is the last positional reading of the vehicle at time T2. By appropriately
8 manipulating the latitude, longitude, and altitude readings of two subsequent readings
9 at time T1 and time T2, it is possible to generate a directional vector and to calculate
10 the velocity of the vehicle.

11
12 Computing the heading and pitch of the current position of the vehicle is
13 accomplished through simple geometry through the use of a lookup table, an example of
14 which is included here for completeness:

15 For locations, $A = (X_1, Y_1, Z_1, T_1)$ and $B = (X_2, Y_2, Z_2, T_2)$

16 T150
Heading: sin() lookup of: $\frac{(y_2 - y_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$

17 T151
Pitch: sin() look up of: $\frac{(z_2 - z_1)}{\sqrt{(y_2 - y_1)^2 + (z_2 - z_1)^2}}$

18 Pitch is correlated against 90° increments for relative attitude correctness.

1 The vector AB defines the directional vector, and the velocity of the vehicle is obtained
2 by:

3

$$\frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}}{(t_2 - t_1)}$$

4 It should be noted that differential GPS (dGPS) data provides more accurate positional
5 information than does GPS data. DGPS data is the result of coupling GPS data with
6 correctional information to reduce the error inherent in the GPS system. A radio signal
7 from a ground-based system is used to "correct" the error found in GPS data. While
8 conventional GPS data has an accuracy of approximately 100 meters, dGPS has a
9 much greater accuracy of approximately 1 to 10 meters. Either GPS data or dGPS data
10 may be used in the present invention.

11

12 The digital computer system 10 correlates the eyepoint position a operator of the
13 vehicle would have with a terrain database location provided by a GPS system in order
14 to generate the virtual image of the real-world terrain following the directional vector of
15 travel in front of the vehicle. This correlation can be accomplished different ways.
16 Pure longitude/latitude data may be used or longitude/latitude data may be converted
17 to Universal Transverse Mercator units or any similar positional locus units.

18

19 The terrain database 18 derived from a GPS system as previously mentioned is
20 preferably based on the highest possible resolution terrain data available from sources

1 such as the United States Geological Society, the Department of Defense, and/or the
2 Defense Mapping Agency. The data of terrain database 18 is typically provided at 30
3 meter spacing and is used by Image Generation Processing block 24 to generate the 3-
4 D image seen on Display block 26. The terrain data included in terrain database 18 is
5 a subset of the data contained in Positional Information block 14 which is received from
6 GPS Unit block 12. Nonetheless, the number of data points represented by terrain
7 database 18 is quite staggering. Assuming that terrain database 18 is a sectional chart
8 having a size of 600 NM (nautical miles) x 400 NM with a resolution of 30 meter
9 spacing, a total of 914,628,720 data points are represented! Obviously this represents
10 too many data points to fit onto a single CD and additionally would require quite a bit of
11 access time upon power-up of the digital computer system.

12
13 The terrain data contained within Terrain Database 18 is used to pre-generate
14 terrain database 18 of the real-world terrain of the applicable travel plan and is put onto
15 a storage device, such as a CD-ROM, that is made available to the digital computer
16 system 10 upon power-up. Upon power-up of the digital computer system 10, the
17 system 10 reads the GPS position, including directional vector information, and
18 generates a 3-D scene depicting the forward view of the vehicle in the terrain.

19
20 Terrain Database 18, in addition to containing GPS terrain information, might
21 also contain sectional chart information about objects such as wires, frequencies,

1 restricted airspace, control zones, landmarks such as towers etc. This sectional chart
2 information is integrated into the terrain database such that can be displayed to the
3 operator upon request. The sectional chart information is used to add
4 transparent/translucent cylinders or objects of "color" around controlled zones and/or
5 restricted zones for the sectional area through which the vehicle is currently traveling.
6 Referring to **Figure 2**, an illustration of the controlled and restricted zones for a
7 particular terrain, such as airspace, through which the vehicle operator is traveling is
8 shown.

9
10 In addition to the sectional chart information and terrain information provided by
11 terrain Database 18, the digital computer system 10 may be provided with additional
12 information at Other Inputs block 22. Thus the digital computer system 10 can also
13 acquire radar input from either an on-board weather radar system or from an on-board
14 TCAS (Traffic Collision Avoidance System) thereby having the ability to incorporate
15 weather conditions or information concerning the location of other vehicles in the
16 region into the generated 3-D image. Such additional information provided by Other
17 Inputs block 22 is incorporated with the terrain database and sectional chart
18 information by Image Generation Processing block 24. As can be seen in Figure 2, the
19 information concerning sectional chart information, terrain information, and other
20 parameters is extremely valuable to air traffic control management.

1 The positional information derived by Location Calculations block 16 from data
2 received from Position Information block 14 is used in conjunction with the terrain
3 database by Image Generation Processing block 24 to create the 3-D image.

4
5 The 3-D image produced by Image Generation Processing block 24 and shown
6 at Display block 26 is a depiction of the terrain in front of the vehicle with the light
7 source at 12:00 "high-noon" and at infinity. This default lighting condition permits the
8 Display block 26 to always display a scene relative to "ideal" conditions, regardless of
9 the actual conditions which might exist outside the vehicle. The lighting angle condition
10 used by the present invention is illustrated in **Figure 3**.

11
12 The field of view (FOV) contained in the 3-D image generated by Image
13 Generation Processing block 24 is selectable within given parameters. The rendered
14 FOV is selectable from 60° to 145°, horizontal HFOV (HFOV) and vertical FOV (VFOV).
15 The FOV is selected with care since too large a FOV value may cause the scene to
16 appear "fish-eyed" and therefore of little use; too small a FOV value may limit the
17 amount of data displayed making the rendered image unusable. Selectable FOV
18 allows the 3-D image to be put on different sized screens for viewing by the operator.
19 *a* Examples of a 90° HFOV and a 90° VFOV are illustrated in ~~Figure 4~~ ^{*Figures 4A and 4B.*}

1 It should be noted that the distant terrain shown in the 3-D image generated by
2 Image Generation Processing block 24 is generated as a function of the speed of the
3 vehicle. Typically, the distant terrain represents the terrain a given number of seconds
4 from the vehicle's present position along the vehicle's directional vector of travel. The
5 distance parameter of the 3-D image is calculated in real-time so as to allow the digital
6 software system 10 to be used with all types of vehicles, including both air and ground
7 vehicles.

8
9 The 3-D image generated by Image Generation Processing block 24 is a
10 representation of the terrain that may be based upon polygonal or fractal image
11 technology. A fractal representation is based upon discrete points and thus generally
12 has a higher resolution image than a filled 3-D polygonal image. For a polygonal filled
13 3-D image, a fairly simple calculation on each polygon in the rendered scene can result
14 in a distance coefficient from the vehicle to the intersection of the plane of the polygon.
15 The render engine of Image Generation Processing block 24, as previously discussed,
16 is code that will generate the 3-D image based upon both terrain data and eyepoint
17 position. In the case of a polygonal filled 3-D image, the render engine is able to
18 translate the polygon list into the 3-D image.

19
20 From the rate of travel of the vehicle, it can then be determined if the polygon
21 lies within another configurable parameter, the "safe-distance" bubble of the vehicle.

1 The "safe-distance" bubble parameter is set by the operator of the vehicle and allows
2 the digital computer system 10 to be easily used in conjunction with vehicles of different
3 sizes, such as with a smaller, slower vehicles or faster, larger vehicles. After the size
4 of the "safe-distance" bubble parameter has been set by the operator, should a polygon
5 within the 3-D image come within the "safe-distance" bubble of the vehicle, an audible
6 and/or visual indicator such as an alarm will inform the operator. The bubble
7 intersection caused by a polygon invading the safe area established by the "safe-
8 distance" bubble parameter that causes the audible and/or visual indicator to enunciate
9 is shown in **Figure 5**.

10
11 In the 3-D image presented to the operator of the vehicle, the polygons of that
12 image have color, texture and other indicators which indicate what type of surface is
13 being represented. For instance, Dark Blue may be representative of water, Green-
14 Land representative of Sky-Blue, Gray representative of Buildings or other protruding
15 land masses, and White representative of surfaces above the "tree-line". Since the
16 database shall be generated prior to "run-time" and shall be stored on a storage
17 device, such as a CD-ROM or other storage device, the color, texture, and other
18 indicators conveyed by the polygon is pre-determined and used by the 3-Dimensional
19 render engine provided by Image Generation Processing 24 at run-time. Coloring the
20 polygons allows for a "baseline" color before any shading has occurred. Subsequent
21 shading provides motion queuing to the operator of the vehicle as the vehicle traverses
22 through the database.

1
2 The polygons of the 3-D image are defined by taking 3 position points from the
3 terrain database 18 in order to generate a flat surface for the render engine
4 represented by Image Generation Processing 24 at that point in the 3-D image. By
5 using multiples of these triplets of terrain data, an fairly accurate rendition of the
6 surface can be developed by the Image Generation Processing 24. The definition of
7 the polygons of the 3-D image by 3 position points is illustrated by **Figure 6**.

8
9 The digital computer system 10 can optionally display a "cross-hair" in the center
10 of the display which depicts the projected flight path of the vehicle. Should this cross-
11 hair intersect with a rendered polygon inside the safety bubble, a visual and/or audible
12 alert will either flash or sound requiring the operator to acknowledge this intersection.
13 The device allows the operator to select either a cockpit view or a trailing view, which
14 depicts a view of the vehicle in the 3-D scene as seen from behind the vehicle.
15 Obviously, the 3-D image produced by Display block 26 should be within easy viewing
16 distance of the operator in the vehicle.

17
18 The operator of the vehicle uses the digital computer system of the present
19 invention when nighttime or other restricted visibility conditions precipitate the need for
20 the operator to be able to "see" the terrain over which the vehicle is traveling in spite of
21 the restricted visibility conditions. The present invention is not intended to be used as

1 the sole navigational device in inclement weather or lighting conditions, but rather
2 serves as a supplemental device to assist conventional IFR navigational devices. The
3 operator of the vehicle is to use the present invention when questions of location, or
4 outside conditions warrant the use of the device to "see" into otherwise blind
5 conditions. Because operation of the digital computer system is independent all other
6 navigational instruments, save for the GPS system on-board the vehicle, the digital
7 computer system is capable as serving as a secondary back-up device for all other
8 navigational instruments on-board the vehicle.

9
10 While the invention has been particularly shown and described with reference to
11 a preferred embodiment, it will be understood by those skilled in the art that various
12 changes in form and detail may be made therein without departing from the spirit and
13 scope of the invention.